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ABSTRACT

This paper is a distillation of research findings on clinical problem-solving over the past decade. These findings are summarized by means of three basic concepts which describe a rudimentary theory of clinical problem-solving performance and instruction: (1) the principle of case simulation--valid clinical problem-solving behavior can be induced by simulated cases presented to clinicians; (2) the principle of clinical simulation--the problem-solving behavior of clinicians is probabilistically dependent on clinical memory, clinical strategies, and the case; (3) the performance evaluation and instructional corollaries of the Inquiry Theory--clinical problem-solving performance can be measured and improved by providing external aids to clinical memory or strategy, training aids for them, and combinations of both. Discussed in the paper are reported findings associated with these three basic concepts and the set of computer programs (The Basic Management Information System) developed by the authors and fellow researchers in studies of the Inquiry Theory. A bibliography is included. (Author)

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THE INQUIRY THEORY:

AN INFORMATION-PROCESSING APPROACH TO CLINICAL PROBLEM-SOLVING RESEARCH AND APPLICATION

by John F. Vinsonhaler,
Christian C. Wagner, and Arthur S. Elstein

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THE INQUIRY THEORY:

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John F. Vinsonhaler, Christian C. Wagner,
and Arthur S. Elstein*

Introduction

Philologists seem to gain a special insight into the true nature of scholarly or scientific work. For example, Taber's (1973) medical and Webster's unabridged dictionaries both include two old, if not ancient, definitions which describe the subjects of clinical theory and research with startling accuracy. Both definitions concern the same word root. "Clinical — pertaining to the teaching of medicine by examining and treating patients in the presence of students."

Our problem concerns the psychology of clinical problem solving and clinical learning: the sometimes obscure processes by which clinicians diagnose and treat and the manner by which they learn this remarkable trade.

The history of this study probably begins with Nash (1954) and his diagnostic slide rule, a mechanical device for associating signs and symptoms with potential diagnostic categories. Certainly, Nash was one of the first to attempt to formulate a theoretical base for empirical observations of clinical problem solving.

Research on clinical problem solving has been actively pursued over the

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past two decades under a variety of names. One area of concentration has dealt with computer-assisted diagnosis and treatment (Kleinmuntz, 1968). Another area concerns the use of patient simulations for training and evaluation in medical education (McGuire and Solomon, 1971). Our research enters the field by way of a third approach — the direct study of the behavior of clinical problem solvers and the development of a rigorous theory for the prediction of such behavior. For the past five years we have been concerned with the development of a formal theoretic structure which could integrate the many concepts and empirical findings on clinical problem solving. The structure we developed is referred to as the Inquiry Theory of Clinical Problem Solving.

The purpose of this paper is to summarize briefly the most recent version of the Inquiry Theory and the system of computer programs which support research and applications of this theory (The Basic Management Information System, BMIS). First, two critical theoretic principles will be abstracted from the more complete discussions of the Inquiry Theory and BMIS. These principles will be defined, related to research findings, and illustrated by computer print-out. Next, two important corollaries of these principles will be discussed in the same manner. For more complete discussion of this work the reader may consult Medical Problem Solving: An Analysis of Clinical Reasoning (Elstein, Shulman, & Sprafka, in press) and the BMTS documentation (Vinsonhaler & Wagner, 1977).

The Clinical Encounter

Before considering concepts abstracted from the Inquiry Theory, the basic definitions and parameters of the theory must be established. The phenomenological base of the research is summarized in the figure below.

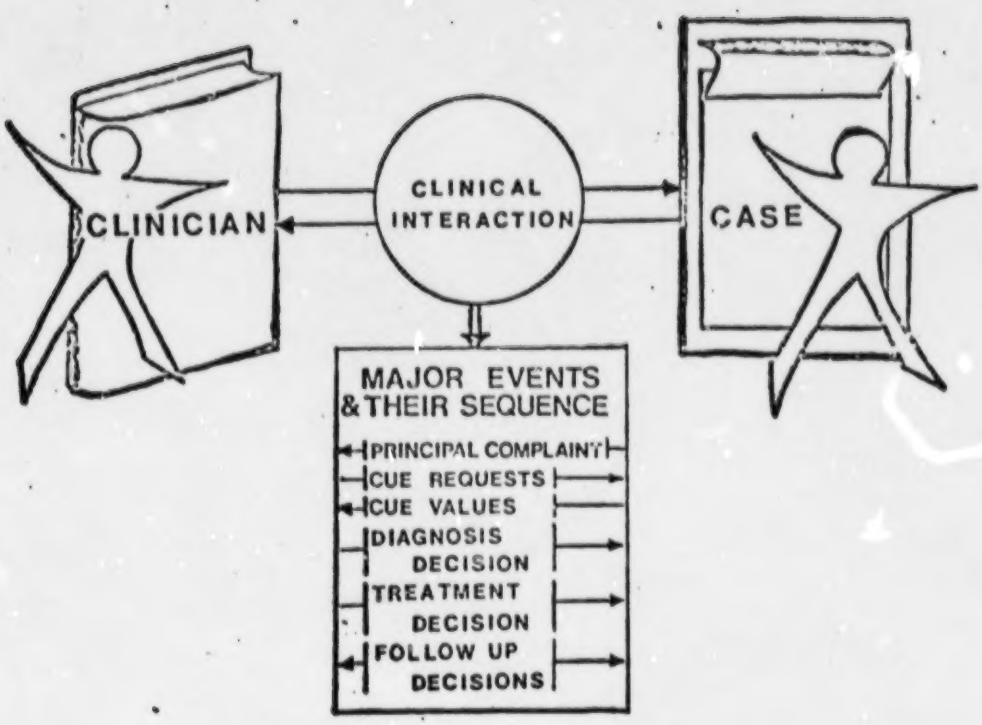


Fig. 1 The Clinical Interaction

The clinical encounter comprises the behavioral domain addressed by the Inquiry Theory. Clinical encounter may be defined as the set of events occurring while a clinician (e.g., a physician, a reading clinician, a teacher, or a trouble shooter) attempts to solve some difficulty of a case (a patient or patient record, a client, a student, or a system) by making two fundamental decisions: (1) the diagnosis (Dx: What is the problem — the current state of the case?); and (2) the treatment (Rx: What action can be taken to solve the problem? What will get the client/case into a more desirable state?).

The result of the encounter is an interaction between clinician and case which occurs over a fixed (finite) period of time. The key behaviors usually observed in research on clinical problem solving are summarized in Figure 1. The direction of interaction is indicated by arrows.

The Inquiry Theory, like many other approaches, attempts to predict only recurrent aspects of the clinical interaction — the features observed when several physicians interact with the same case or a single physician interacts with several cases.

The Clinical Case

The first principle that must be considered concerns the simulation of cases or patients. To achieve a scientifically acceptable level of objectivity in the study of the clinical encounter, case simulation is mandatory; otherwise, there is no basis for replication because no "real" case can be presented in exactly the same manner to more than one physician.

Inquiry Principle of Case Simulation

As illustrated in Figure 2, one of the two basic tenets of the Inquiry Theory is that cases can be effectively simulated by providing the clinician with sets of requested information. Thus, for purposes of this theory, a CASE or CASE RECORD may be defined simply as a collection of:

1. Clinical problems defining the diagnostic and therapeutic task presented by the case;
2. The cue names and values defining the data base available for diagnostic and therapeutic decision making; and
3. The cue names and values defining changes in the data base to be expected from different treatments available to the clinician and the passage of time.

This conception concentrates upon the "intellectual" aspects of medicine. The affective domain is largely excluded. It is not that we fail to appreciate the impact of emotions in proper clinical care, but rather we appreciate all too well the unique advantage humans have over computers in handling affective problems.

Related Research

Some workers in computer patient simulation have emphasized the need for highly realistic natural language interaction between the student and the simulated case. For example, the "Case" project (Harless, Drennon, Marxer, Root, Wilson, & Miller, 1973) expended great effort in the preparation of software which supports this interaction. The difficulties with this approach have been the same as those which ultimately crushed so many natural language R & D projects — costs and user acceptance. First, the production of medical cases tends to be extremely costly in terms of both human effort and money. Second, many people see little advantage in chatting with computers, especially when they must use a typewriter-teletype to do so (Friedman, 1973). Medical students especially seem to prefer more directed interactions which require less "interaction" and provide more guidance (DeDombal, Horrocks, Chamb, & Storr, 1974, 247-252).

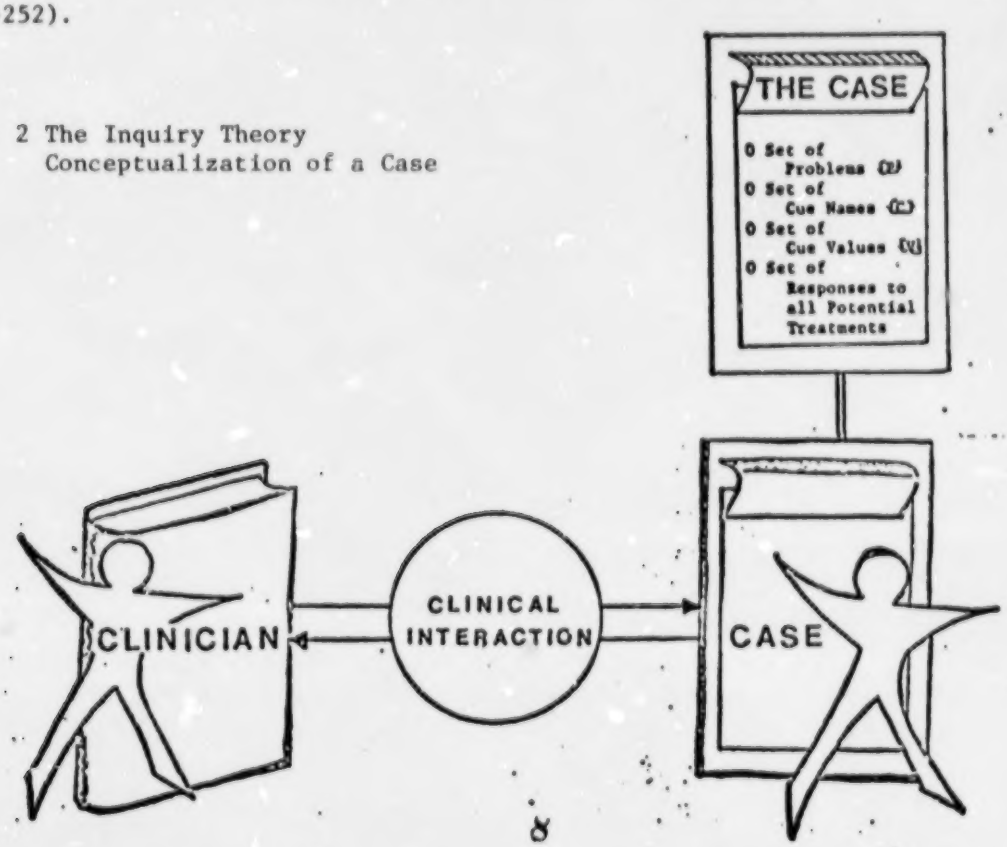


Fig. 2 The Inquiry Theory Conceptualization of a Case

Our concepts of patient simulation follow the arguments of Friedman (1973) at Wisconsin and DeDombal et al. (1974) at Leeds that significant features of clinical problem solving skills can be taught without completely simulating the natural language interaction. Like the Wisconsin system, we minimize required input by students and maximize the ease of preparing cases by R & D teams instead of physicians. Attempts have been made to extend the Wisconsin approach by eliminating from the simulations all but a few restrictions on the language of the interaction between a case and a physician.

The SIMCASE Concept

The cognitive characteristics of a case may be viewed as a set of values associated with a list of cues, a set of problems that are reflected in altered cue values, and a set of responses to all possible treatments. Simulating a case, then, can be accomplished by simulating these individual elements. In BMIS, such a simulation is called a SIMCASE (SIMulated CASE). An interaction with a SIMCASE is illustrated below, where the BMIS computer is acting as the source of information about the patient. A SIMCASE is created by inputting cue names and values to the BMIS programs, which then combines them with "standard" information to generate a case.

```
#$RUN WBSW:BMISX+*OLDFIO 1=WBSW:FMEDIFT 2=WBSW:FMEDDFT
#EXECUTION BEGINS

                THE BASIC MANAGEMENT INFORMATION SYSTEM VERSION 1.1
                      THE INSTITUTE FOR RESEARCH ON TEACHING
                           MICHIGAN STATE UNIVERSITY
                                    1976

?*$cass

ENTERING THE CASE SIMULATION SUBSYSTEM

?*$list cases
THE ALLOWED CASES ARE:

#SIMCASE,JAMES WALKER
     JAMES WALKER IS A 47 YEAR OLD WHITE MALE WITH A COMMON
```

PROBLEM IN INTERNAL MEDICINE. THIS CASE IS RELATED TO THE MSU FOCAL PROBLEMS FOR PHASE II, TERM 2 STUDENTS.

$SIMCASE,JENNIFER JONES
JENNIFER JONES IS A 51 YEAR OLD WHITE FEMALE WITH A PROBLEM IN INTERNAL MEDICINE. THIS CASE IS RELATED TO THE MSU FOCAL PROBLEMS FOR PHASE II, TERMS 2 STUDENTS.

?*$list vocabulary
THE ALLOWED KEYWORDS ARE:

ABDOMEN
ADULT INFECTIOUS DISEASES
ALLERGIES
.
.
.
VITAL SIGNS
WBC

?*$simcase
?*$name jennifer jones
?*$go

BEGINNING CASE SIMULATION

THE ENCOUNTER WITH THE CASE BEGINS:
THE PATIENT WAS REFERRED BY ANOTHER PHYSICIAN FOR GASTOINTESTINAL PROBLEMS.

ENTER KEYWORD
?general appearance
THE PATIENT IS A MARKEDLY OBESE, MIDDLE AGED, WHITE FEMALE. SHE HAS SMALL VESICULAR PAPULES OVER THE FACE AND UPPER THORAX. THE NAILS ARE TAN AND YELLOWISH.

ENTER KEYWORD
?abdomen
STRIKING HEPATOSPLENOMEGALY. VIRTUALLY ALL OF THE LIVER WAS BELOW THE COSTAL MARGIN AND WAS MEASURED ALMOST 18 CM IN THE MID CLAVICULAR LINE AND 15 CM IN THE MID LINE. THE LIVER WAS FIRM. THE SPLEEN WAS 7-8 CM BELOW THE COSTAL MARGIN RATHER MEDIALLY AND QUITE FIRM. THERE WERE NO DILATED VENOUS COLLATERALS OF THE ABDOMEN WALL.

ENTER KEYWORD
?vital signs
THE PATIENT IS 5 FEET 3 INCHES TALL AND WEIGHS 150 POUNDS. HER ORAL TEMPERATURE IS 98.6. PULSE IS 75 AND REGULAR. RESPIRATION RATE IS 22/MINUTE. BLOOD PRESSURE IS 180/100 RIGHT ARM RESTING.

ENTER KEYWORD
?liver biopsy
A LIVER BIOPSY OF THE PATIENT REVEALED A FATTY CHANGE, BRIDGING, ADVANCED CIRRHOSIS, LIMITING PLATE DISRUPTION, FIBROSIS AND FOCAL NECROSIS.

```
ENTER KEYWORD
?*$diagnose

ENTER YOUR DIAGNOSES (END LIST WITH BLANK LINE)
?hepatitis
?high blood pressure
?

END OF CASE SIMULATION
?*$finish
#EXECUTION TERMINATED
```

The Clinician

The second principle of the Inquiry Theory concerns the major factors which govern the behavior of a physician in a clinical encounter.

The Inquiry Principle of Clinician Simulation

As illustrated in the figure below, we postulate that the major events in the clinical interaction are determined probabilistically by the CASE and the CLINICIAN's MEMORY AND STRATEGY. The clinician's memory (Clinical Memory)

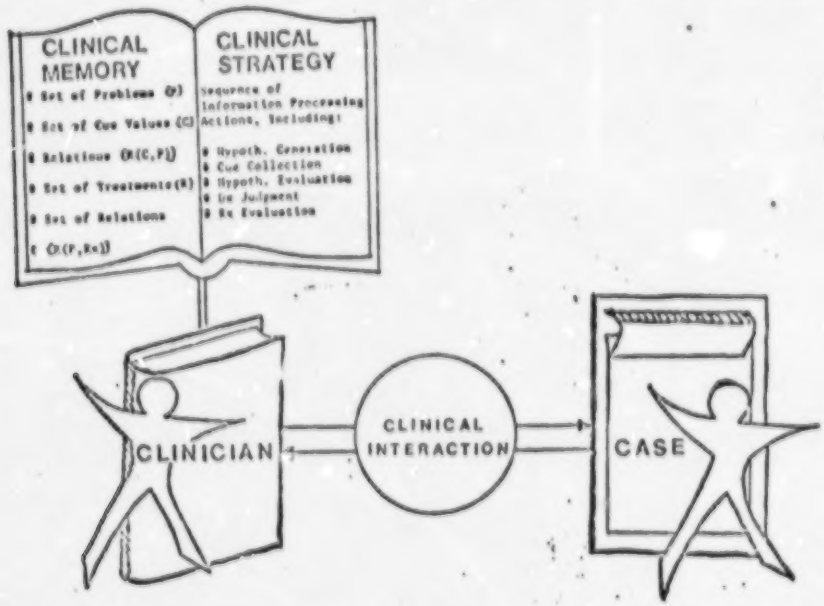


FIGURE 3. The Inquiry Theory Conceptualization of a Clinician

consists of problem, cue, prescription, and treatment descriptions. Further, it contains a number of important relations, including: (1) a set of relations between cue and problem descriptions used to infer the presence of problems in a given case based on the cues already collected; (2) a set of relations between problem and cue descriptions used to determine which cues should be collected next to confirm or disconfirm the hypotheses currently under consideration; (3) a set of relations between problems and treatments used to evaluate and select treatment plans for a given case and diagnosis; and (4) a set of relations between treatments and prescriptions used to define the specifics of case management for a particular case and treatment plan.

The clinician's strategy (Clinical Strategy) consists of a planned sequence of information-gathering and information-processing tasks using the clinical memory to make decisions about diagnosis and treatment. Our set of information-processing tasks was derived from empirical studies of clinical problem solving with simulated cases (Elstein et al., in press). The tasks include:

Cue acquisition. This process consists of deciding which cues should be collected in the medical history, physical examination, and laboratory work-up, and the collection of cue values for those selected. Cues may be selected on one of two bases: first, as a means of confirming or disconfirming one or more competing hypotheses about the patient's problem or second, according to some information-gathering heuristic, e.g., according to a work-up "routine" by body systems.

Hypothesis generation. This process consists of retrieving from memory a number of problem formulations based on a limited number of cues. Hypotheses generated early are used in part to guide the subsequent work-up. The set of problem formulations retrieved is based upon the relations between cues and

problems R(C,P) that are part of the clinician's memory.

Cue interpretation. Cues are evaluated in terms of their fit to specific hypotheses.

Hypothesis evaluation and diagnosis judgment. This process consists of estimating the likelihood of each hypothesis under consideration. Two separate levels may be distinguished: First, unlikely hypotheses are eliminated from the set under consideration; second, one or more of the hypotheses may be accepted as the diagnosis if the likelihood of those problems is sufficiently high. Likelihood is calculated on the basis of the relations between problems and cues R(P,C). Several methods of calculating the likelihood of hypotheses have been successfully used, including: Bayesian probability, multiple regression, and simple algebraic summation of weights (Slovic & Lichtenstein, 1971; Dawes & Corrigan, 1974).

Treatment evaluation. This process consists of estimating the expected gain for each of the treatments available for the patient's diagnosed problem. Expected gain is calculated on the basis of the relations between the problem and available treatment plans R(P,T). These relations may include precautions and contraindications appropriate to the patient or case.

Prescription selection. After the treatment plan is selected, the relations between treatments and prescriptions R(T,Rx) are used to write out the specifics of the case management.

Clinical memories have been developed in a variety of ways, but all approaches seem to have one thing in common; postulations of a memory storage element (e.g., record or list) for each medical problem in the clinician's memory, for each cue (symptom or sign or laboratory test) in the clinican's repetoire, and for each treatment or prescription used by the clinician. We conceive of problem representations as associating problems with cue names (i.e., Given a set of symptoms, what cues should be collected?); cue representations as relating cue

names to cue interpretation and collection routines; and treatment representations as associating treatments with problems. The present version of the Inquiry Theory computer programs also has the capability of altering an overall strategy and switching to a substrategy upon the generation of any particular hypothesis. For example, one substrategy is a procedure for checking out neoplasms when an unexpected abdominal mass is discovered while performing a routine abdominal examination.

Relevant Research

The representation of a clinical encounter as an interaction between a case and a clinician's memory and strategy derives from empirical studies of clinical problem solving. By conceptualizing CLINICAL MEMORY and STRATEGY from an information-processing perspective, several features of this reasoning may be seen to be particular instances of more general principles of the psychology of thinking. The principles of special importance in this study are as follows:

Use of a problem space. Problem solving is characterized by (1) the representation of a complex problem by a simplified problem space (Newall & Simon, 1972), (2) the structuring of the problem space to determine the information-processing activities to be used in solving the problem, and (3) by the accuracy of problem representation and the effectiveness of the actions taken to achieve a goal determining success.

The hypothetico-deductive method. In clinical problem solving, the vast complexity of the diagnostic problem is accommodated by (1) the early generation of tentative diagnostic hypotheses used by the clinician to structure the problem space within manageable limits, and (2) the use of the hypothetico-deductive method to select the cues to be collected in the clinical encounter (Elstein

et al., in press).

Strategies for handling complexity. Given the limitations on the number of hypotheses and cues that can be retained in immediate memory, the clinical problem solver tends to use strategies for reducing the complexity of problem space. (1) Linear Problem Solving: testing one or two hypotheses at a time, thus reducing the size of the problem space or making it possible to find space for new hypotheses or more adequate reformulations. (2) Problem Space Reorganizations: revising the problem domain by "chunking" or revising the diagnostic concepts. Methods observed include reformulation of the problem, conversion to a set of problems related to predecessors, beginning with general problem and proceeding to specific, and beginning with specific complaints and proceeding to general problems.

Hypothesis generation and testing. Hypothesis generation is characterized by (1) initial problem formations (hypotheses) generated by associations of a single cue to a hypothesis, a set of cues to a hypothesis, or a hypothesis to a hypothesis (selective, systematic cue collection is more closely associated with hypothesis evaluation than with generation); and (2) the number of hypotheses tested simultaneously (usually four or five with a maximum of six or seven hypotheses).

Possible memory structures for these problem formulations include lists of cue findings stored under diagnostic labels. The adequacy of these lists for different hypotheses (problems) varies within a single physician as well as between physicians, which may be one reason why physicians are inconsistent across cases.

According to studies at McMasters University (Neufeld, Norman, Feighter, & Barrows, 1975; Barrows, Feighter, Neufeld & Norman, 1975), hypothesis generation and testing behavior may be further characterized by the following:

(1) early generation of hypotheses — 55% of the hypotheses were considered in the first 12% of the encounter, 78% in the first 25% of the encounter. (2) early elimination of hypotheses — there is very little modification of hypothesis pool in the last 50% of the encounter (94% of hypotheses considered in the last 50% of the encounter are retained).

Cue interpretation. The Inquiry and McMasters studies indicate cue interpretation is characterized by subjective weighting of cues for given hypotheses. Cues seem to be weighted on a three-point scale that confirms or disconfirms a hypothesis, or labels it as non contributory. The scheme is a simplified approximation of Bayes' Theorem. Accuracy of cue interpretation is directly related to accuracy of diagnosis outcome and independent of thoroughness of cue acquisition.

Cue collection. According to the same McMaster studies, (1) most of the history (68%) is elicited in the first half of the encounter; (2) most of the physical cues are elicited in the third quarter of the encounter; and (3) early acquisition of findings is documented as follows: 50% of the total findings are elicited in the first 25% of the encounter, 56% of the supercritical and 53% of the critical findings are elicited in first 25% of the encounter.

The SIMCLIN Concept

The Inquiry Theory of clinical problem solving states that the cognitive characteristics of a clinician are determined by the interaction of his clinical memory of problems, cues, treatments, prescriptions, and relationships among them, and his clinical strategy for the sequencing of a set of information-processing tasks. Simulating a clinician can then be accomplished by simulating a memory and strategy and the interaction between the two. In BMIS, such a simulation is called a SIMCLIN (SIMulated CLINician). A SIMCLIN is produced by inputting a clinical memory and one or more strategies. As noted before, strategies can be linked to problems so that a SIMCLIN can pursue an overall

approach while investigating special problems by means of substrategies linked to particular findings (an abnormal abdominal mass, for example). The printout below illustrates a SIMCLIN's interaction with a medical researcher who is investigating a case record. The interaction mode illustrated leaves cue interpretation to the researchers. Other modes are available in BMIS.

```
#$RUN WBSW:BMISX+*OLDFIO 1=WBSW:FMEDIFT 2=WBSW:FMEDDFT
#EXECUTION BEGINS

                THE BASIC MANAGEMENT INFORMATION SYSTEM VERSION 1.1
                    THE INSTITUTE FOR RESEARCH ON TEACHING
                        MICHIGAN STATE UNIVERSITY
                                1976

?*$clss

 ENTERING THE CLINICIAN SIMULATION SUBSYSTEM
?*$strategy
?*$name clinic
?*$memory
?*$name clinic
?*$diagnose
?*$case is online
?*$go

 BEGINNING CLINICAL SIMULATION

 PLEASE INPUT THE SYMPTOMS AND SIGNS FOR THE INITIAL
 CONTACT WITH THIS CASE.  (END LIST WITH A BLANK LINE)
?the patient, an obese caucasion male over the age of 40, complains of
?headaches, fatigue, and weakness.
?
IS THE PATIENT'S DIASTOLIC BP HIGH?
```

```
?yes
HAS THE PATIENT HAD ABDOMINAL PAIN?
?yes
HAS THE PATIENT HAD EXCESSIVE ALCOHOL INTAKE?
?no
HAS THE PATIENT HAD JAUNDICE?
?yes
IS THERE A FAMILY HISTORY OF LIVER DISEASE?
?yes
DOES THE PATIENT HAVE AN ENLARGED LIVER?
?yes
IS THE PATIENT'S LIVER FIRM?
?yes
DOES THE PATIENT HAVE AN ENLARGED SPLEEN?
?yes
IS THERE A FAMILY HISTORY OF HYPERTENSION?
?no
IS THE PATIENT'S DIASTOLIC BP REPEATEDLY HIGH?
?yes
DOES THE PATIENT HAVE HYPERTENSIVE RETINOPATHY?
?yes
**********************************************************************
THE SIGNS AND SYMPTOMS SEEM TO INDICATE THAT THE CLIENT'S PROBLEM(S) INCLUD
HYPERTENSION

HAS THE PATIENT LOST HIS APPETITE?
?no
HAS THE PATIENT'S TEMPERATURE BEEN HIGH?
?no
DOES THE PATIENT'S LIVER BIOPSY SHOW FIBROSIS?
?yes
DOES THE PATIENT'S LIVER BIOPSY SHOW FATTY CHANGE?
?yes
DOES THE PATIENT'S LIVER BIOPSY SHOW ADVANCED CIRRHOSIS?
?yes
DOES THE PATIENT'S LIVER BIOPSY SHOW BRIDGING?
?yes
DOES THE PATIENT'S LIVER BIOPSY SHOW LIMITING PLATE DISRUPTION?
?yes
**********************************************************************
THE SIGNS AND SYMPTOMS SEEM TO INDICATE THAT THE CLIENT'S PROBLEM(S) ARE:
PRIMARY HYPERTENSION
PORTAL CIRRHOSIS OF THE LIVER

 END OF CLINICAL SIMULATION
?*$finish
#EXECUTION TERMINATED
```

Clinical Evaluation/Instruction

Thus far, ideas have been developed regarding the structure of clinical problems and the information processing of clinicians. We have shown how these ideas are incorporated in a system for computer simulation of clinical reasoning. We will now consider some implications of these notions for evaluation and training within medicine.

The Performance Evaluation and Instruction Corollaries

The Performance Evaluation Corollary. If the clinician's portion of the clinical interaction is determined by clinical memory and strategy, it follows that performance evaluation based upon the interaction must be determined by clinical memory and strategy. Hence, the Performance Corollary: Reliable, valid evaluations of clinical problem-solving performance are probabilistically determined by the CASE and the CLINICIAN'S MEMORY and STRATEGY. By valid evaluations, we mean evaluations requiring accurate, non-ambiguous case records, non-ambiguous criteria for measuring clinical performance, and clinical preceptors with special competence for the particular case.

The Instruction Corollary. If clinical performance is probabilistically determined by the clinician's memory and strategy, it follows that clinical performance may be improved by alterations in clinical memory and strategy. Hence, the Instruction Corollary: Clinical problem solving performance may be improved by (1) providing performance aids to augment clinical memory and strategy; (2) providing training and feedback aids for the acquisition of more accurate and effective clinical memories and strategies; and (3) providing combinations of training and decision aids.

The two corollaries are summarized in Figure 4.

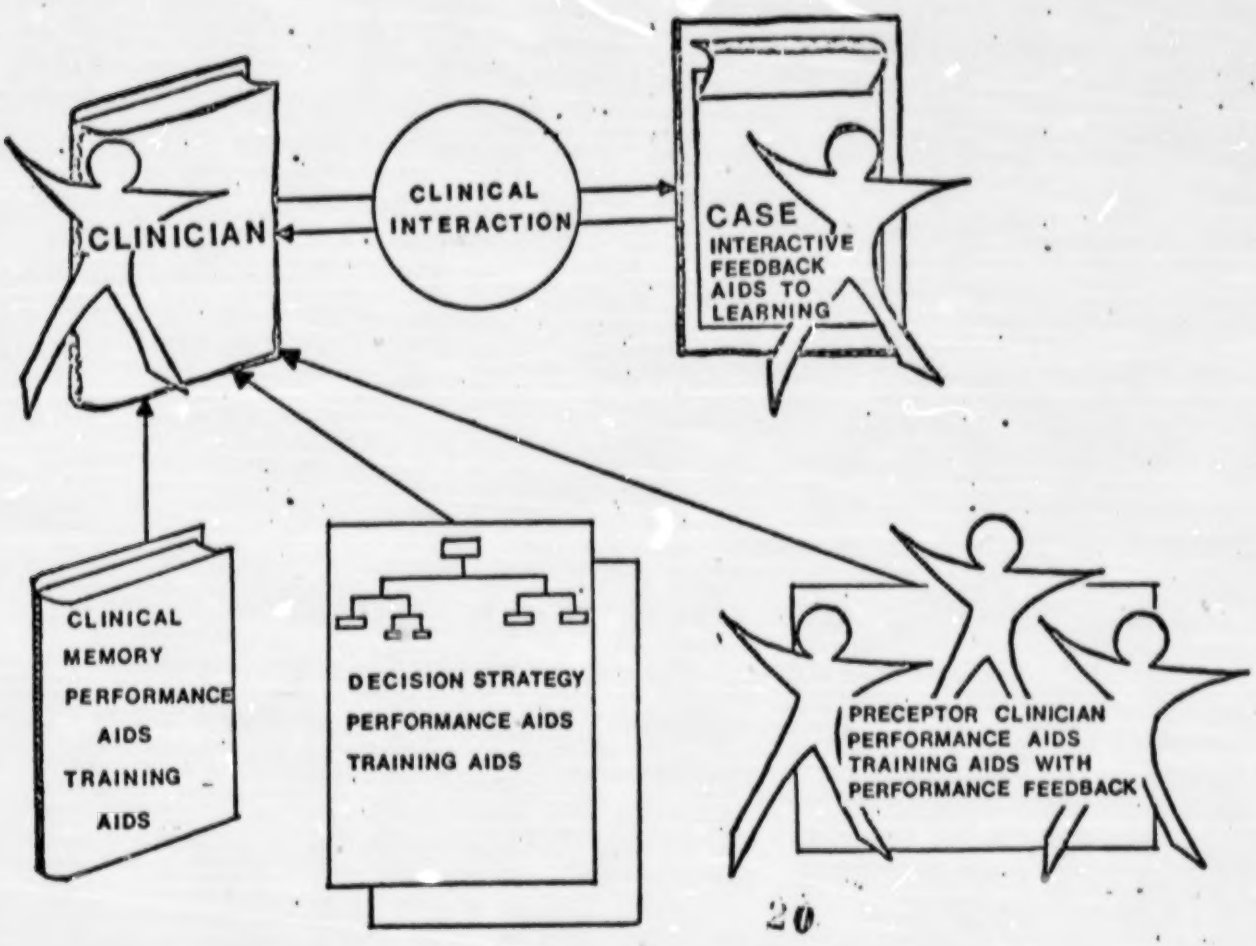
Related Research

Regrettably, research on the educational applications of information-processing theories of clinical reasoning is much more limited than research on the theories themselves. The key studies which led to the formulation of the Performance Evaluation/Instruction Corollaries are briefly summarized below.

To begin with, consider the studies attempting to improve diagnostic performance by the use of computer-aided diagnostic procedures. Two research programs in particular were of prime importance to our work since they indicated the practicality of using computers in the real world of a clinic.

The first set of studies was conducted in the Leeds Medical Center in the United Kingdom.

Fig. 4 The Performance Evaluation and Instructional Corollaries


CLINICIAN
CLINICAL INTERACTION
CASE
INTERACTIVE FEEDBACK AIDS TO LEARNING
CLINICAL MEMORY PERFORMANCE AIDS TRAINING AIDS
DECISION STRATEGY PERFORMANCE AIDS TRAINING AIDS
PRECEPTOR CLINICIAN PERFORMANCE AIDS TRAINING AIDS WITH PERFORMANCE FEEDBACK

The most dramatic study (DeDombal, 1973, pp. 184, 433-440; DeDombal & Horrocks, 1974, pp. 581-585) included a real-time controlled trial that was carried out on a consecutive series of 552 unselected patients. This trial included all patients who came to the Department of Surgery between January 1971 and August 1972 with abdominal pain of less than one week's duration. The preoperative diagnosis of the most senior clinician in each case was accurate in 87% of the patients studied. Using the same information (and producing its diagnosis before the operation), the computer-aided system proved to be accurate in 98% of the cases. In a subsequent study, the Leeds group found that training with the computer-aided diagnostic system significantly improved students' clinical performance as well.

The second set of studies in computer-aided diagnostic concerns is the MEDITEL system (Barnes, Tunnessen, Worley, Simmons, & Ringe, 1974). The data bank for the system includes 1,500 diagnoses in pediatrics. Since many of these have diagnostic names that are categorical, the data bank encompasses nearly all pediatric diagnoses of systemic illness. There are approximately 650 abnormal symptoms, physical findings, and laboratory results in the MEDITEL vocabulary. Of these, 75 are historical, 375 are physical findings (including 60 roentgenographic findings), and 200 are laboratory findings. All of the vocabulary consists of commonly used medical terminology that has been selected for the potential to distinguish one diagnosis from another. Computer-assisted diagnosis for a given patient is obtained by selecting from the list of abnormal symptoms, physical findings, and laboratory results noted at the time of the initial history and physical examination. These findings are sent, via terminal, to a remote time-sharing computer over telephone lines. The computer systematically searches its data bank, compares the patient's findings with each diagnosis, and selects the diagnoses that should be included in a complete differ-

ential diagnosis. These are listed by the teletypewriter terminal.

Perhaps the most impressive evaluation of MEDITEL was by Swender (1974). In this investigation, MEDITEL was evaluated for its ability to consider a correct diagnosis in cases where the correct diagnosis was not considered in the original differential diagnosis by physicians involved in the patient's care. The computer provided the correct diagnosis in 83% of the 33 cases studied when the information was entered by a physician and in 65% of the cases when the information was provided by a medical secretary.

In summary, research on such computer aids to memory and strategy reaches the following generalizations: Given subjective weights provided by physicians, the accuracy of computer-assisted diagnosis is variable; sometimes equalling physicians, but often less effective (Leaper, Horrocks, Staniland & DeDombal, 1972). Given empirical weights, computers can diagnose more accurately than senior clinicians. However, computer diagnosis has been demonstrated only in limited areas of practice/decision making — abdominal surgery, for example. Finally, student clinicians can benefit from interaction with computerized diagnostic mentors.

A second approach to improving diagnostic or theraputic performance is the attempt to improve them by means of non-computer external aids to memory and strategy. Many studies indicate the effectiveness of decision aids in the form of books of decision-making charts not too dissimilar from the familiar MERCK MANUAL (Holvey, 1972). Essex (1975) reported that medical students provided with decision flow charts were able to improve their performance from 70% agreement to 98% agreement with senior clinicians. Further, while the physicians required an average of 13.7 minutes per case, the students required only 1.9 minutes.

Basically, the results on external memory and strategy aids seem to follow

these generalizations: Decision-making aids to clinical memory and strategy can significantly improve the performance of medical students or paraprofessionals on specific problems for which the aids have been developed (Grimm, Shimoni, Harlan,& Estes, 1975). Under some circumstances, printed decision charts can help paraprofessionals function nearly as effectively as physicians and with greater efficiency.

As a third point on improving diagnostic performance, consider the research findings on performance and strategy which seem to be accounted for by the Inquiry Theory. Among the most important results are the following:

The MSU inquiry studies. Diagnostic success on some medical problems is not highly correlated with success on other problems, i.e., diagnostic accuracy is case specific (Elstein et al., in press) Diagnostic performance is related to the amount of experience during and after medical school, but to little else.

The CBX studies (Hoffman, 1974a & 1974b). Performance criteria do not readily distinguish among clinicians. Diagnostic success is problem dependent (or at least dependent upon knowledge domain).

The McMaster findings (Neufeld, et al., 1976; Barrows et al., 1975) Quantitative studies of clinical performance seem to indicate that only a few criteria are sufficient. The most important criteria for the description of clinical performance are (1) diagnostic commonality; (2) thoroughness; and (3) efficiency. Clinical performance seems to improve as a function of experience under conditions of performance feedback, when performance is measured by commonality or agreement with absolute criteria, e.g., pathologic findings, reaction to treatment, etc.

To conclude these brief research notes, we offer some hypotheses on the nature of clinical learning. Diagnostic learning seems to consist of the fol-

lowing:

1. Development of improved problem descriptions by means of description extension (adding cues to the problem description) and description validation (establishing more valid relations between cues and problems).
2. Development of improved cue descriptions by means of extension (adding cues and cue characteristics) and cue validation (improving the recognition of cue values).
3. Development of strategy structures to control the diagnostic process for individual cases.
4. Improvement in memory and strategy by experience with cases under conditions of feedback on performance in diagnosing and treatment.

The COMPUCEPTORship Concept

The Performance Evaluation and Instruction Corollaries hold many implications for methods to aid clinicians in their training and problem solving. Our present attempt to provide computer support for the application of these corollaries to diagnostic and therapeutic training and problem solving is the COMPUCEPTORship concept. Essentially, the concept is to provide computer support for all aspects of training and performance for clinical problem solving, including computer-aided diagnosis, the production of decision aids for clinical memory and strategy, SIMCASE aids for training, and complex computer-aided instruction (CAI) aids permitting students to interact with SIMCASE problems under the direction of computer preceptors (SIMCLINS) which reflect the best decision-making strategies and memories for the given case, based upon expert opinion. The example given below illustrates this CAI mode of using BMIS. Required input consists of what was described previously as needed for a SIMCASE AND SIMCLIN. Other, more exotic input can be added to COMPUCEPTORs.

```
#$RUN WBSW:BMISX+*OLDFIO 1=FMEDIFT 2=FMEDDFT
#EXECUTION BEGINS

              THE BASIC MANAGEMENT INFORMATION SYSTEM VERSION 1.1
                    THE INSTITUTE FOR RESEARCH ON TEACHING
                        MICHIGAN STATE UNIVERSITY
                              1976

?*$comss

 ENTERING THE COMPUCEPTOR SIMULATION SUBSYSTEM
?*$simcase
?*$name james walker
?*$go

 BEGINNING COMPUCEPTOR SIMULATION

 THE ENCOUNTER WITH THE CASE BEGINS:
    A 47 YEAR OLD WHITE MALE ELECTRICIAN WAS BROUGHT TO THE HOSPITAL
IN A STATE OF ACUTE WITHDRAWAL.  THE HISTORY AS FOLLOWS WAS OBTAINED FROM
RELIABLE FAMILY MEMBERS:
    THE PATIENT HAD BEEN DRINKING APPROXIMATELY ONE QUART OF 86 PROOF
BOURBON EVERY DAY FOR 35 DAYS BEFORE HIS ADMISSION.  DURING THIS TIME,
HIS FOOD INTAKE HAD CONSISTED OF SUBSTANTIAL DAILY AMOUNTS OF EGGS, MILK,
BREAD AND POTATOES.  HE HAD TAKEN TWO OR THREE MULTIVITAMIN CAPSULES DAILY
HE HAD HAD NO VOMITING OR DIARRHEA.

ENTER KEYWORD
?past medical history
     SALIENT FEATURES OF THE PAST HISTORY INCLUDE TWENTY
YEARS OF ALCOHOLISM WITH FREQUENT HOSPITALIZATION FOR ACUTE
INTOXICATION AND WITHDRAWAL WITHOUT OVERT MALNUTRITION.

ENTER KEYWORD
?*$compuceptor hypotheses with 2 cues

ENTER YOUR HYPOTHESES (END LIST WITH BLANK LINE)
?none
?
BASED ON ALL CUES WHICH SHOULD BE COLLECTED FOR EACH
HYPOTHESES, THE LIKELIHOODS OF THE HYPOTHESES UNDER
CONSIDERATION ARE:
RELEVANCE                          POSSIBLE DIAGNOSIS
-------------------------------------------------------------------------
    0.0392 CHRONIC HEPATITIS
    0.1860 PORTAL CIRRHOSIS OF THE LIVER
    0.2647 ACUTE ALCOHOLISM

 THE NEXT MOST IMPORTANT CUES TO COLLECT ARE:
     ENLARGED LIVER
     LIVER BIOPSY
```

```
ENTER KEYWORD
?liver biopsy
     LIVER BIOPSY SHOWS FATTY CHANGE, ADVANCED CIRRHOSIS,
BRIDGING, LIMITING PLATE DISRUPTION, FIBROSIS, AND
FOCAL NECROSIS.

ENTER KEYWORD
?*$diagnose

ENTER YOUR DIAGNOSES (END LIST WITH BLANK LINE)
?acute alcoholism
?cirrhosis of the liver
?
THE COMPUCEPTOR DIAGNOSIS IS;
 ACUTE ALCOHOLISM, CIRRHOSIS OF THE LIVER, ANEMIA

 YOUR PERCENT AGREEMENT IS 66%

  THE DIAGNOSIS YOU FAILED TO AGREE  WITH THE COMPUCEPTOR ON WAS ANEMIA.

 END OF COMPUCEPTOR SIMULATION
?*$finish
 #EXECUTION TERMINATED
```

Discussion and Observations

This paper is a distillation of research findings on clinical problem solving over the past decade. These findings have been summarized by means of three basic concepts which seem to describe a rudimentary theory of clinical problem-solving performance and instruction. The first concept involves the principle of case simulation; realistic, valid clinical problem-solving behavior can be induced by simulated cases presented to clinicians. The second concept concerns the principle of clinician simulation; the problem-solving behavior of clinicians is probabilistically dependent upon clinical memory, clinical strategies, and the case. The third concept involves the Performance Evaluation and Instructional Corollaries of the Inquiry Theory; clinical problem-solving performance can be measured and can be improved by providing (1) external aids to clinical memory or strategy, (2) training aids for clinical memory or strategy, and (3) combinations of external and training aids.

Discussed in the paper are reported findings associated with these three basic concepts and the set of computer programs (BMIS) developed by the authors and fellow researchers in studies of the Inquiry Theory. To complete this discussion, we would like to share a few observations which may suggest future directions for research and development of the theory of clinical problem solving.

To begin with, many of the empirical findings observed in studies of physicians (Elstein et al., in press) seem to be reproducible with our simulated clinicians (SIMCLINs). Further, our SIMCLINs have yielded a number of fascinating predictions of phenomena which, to our knowledge, have not been empirically observed. In one recent study, for example, we explored the effect of reducing the size of a SIMCLIN's memory to approximately that of a human. As the size of memory was reduced, the SIMCLINs studied switched from a parallel to a linear strategy for hypothesis testing; only one or two hypotheses were considered simultaneously, but the complete set was eventually examined and the correct diagnosis obtained. This result depended upon the separation of the diagnostic decision from the decision to continue or halt the diagnostic process. Otherwise, no preprogramming was involved.

In another example, we examined the impact of errors in the history, physical, and laboratory findings on the diagnostic correctness and efficiency of SIMCLINs. Those SIMCLINs which made diagnostic decisions on the basis of the aggregation of findings involving many (often redundant) cues (1) retained accurate diagnostic performance rates in spite of error in the data; (2) tended to become less efficient in the presence of error; and (3) tended to become even less efficient when errors involved cues irrelevant to the diagnosis than when errors involved cues that were relevant. The mechanism for this effect seems to be the generation of greater numbers of incorrect hypotheses in the

case of error in irrelevant cues. These results are tentative since they are based upon a limited set of individual problems available in our data base.

Within the next year, we hope to verify these SIMCLIN findings with a much larger set of medical problems developed by Bordage (1976).

Barnes, L.A., Tunnessen, W.W., Worley, W.E., Simmons, T.L., & Ringe, T.B. Computer-assisted diagnosis in pediatrics. American Journal of Disabled Children, June 1974, 127, 852-858.

Barrows, H.S., Feighter, J.W., Neufeld, V.R., & Norman, G.R. Data gathering, problem solving, and management - Observation of the clinical encounter in time segments. Proceedings, Conference on Research in Medical Education, Association of American Medical Colleges, Washington, D.C. November, 1975.

Bordage, G. Computers and medical diagnostic problem solving. Unpublished master's degree project report. Dept. of Biometry, School of Medicine, Case Western Reserve University, Cleveland, Ohio, June 1976.

Dawes, R.M., & Corrigan, B. Linear models in decision making. Psychological Bulletin, February 1974, 81(2), 95-105.

DeDombal, F.T. Surgical diagnosis assisted by a computer. London: Procedures Royal Society, 1973.

DeDombal, F.T., Horrocks, J.C., Champ, S.E., & Storr, J.E. Simulation techniques and computer-aided teaching of the clinical process: Five years of experience. Medinfo 74 Proceedings, New York: North Holland Publishing Company, 1974.

DeDombal, F.T., & Horrocks, J.C. Computer aided diagnosis: Conclusions from an overall experience involving 4469 cases. Medinfo 74 Proceedings, New York: North Holland Publishing Company, 1974.

Elstein, A.S., Shulman, L.S., & Sprafka, S. Medical problem solving: An analysis of clinical reasoning. Cambridge, Mass.: Harvard Press, in press.

Essex, B.J. Approach to rapid problem solving in clinical medicine. British Medical Journal July 1975, 3, 34-36.

Friedman, R.B. A computer program for simulating the patient-physician encounter Journal of Medical Education, January 1973, 48, 92-97.

Grimm, R.H., Shimoni, K., Harlan, W.R., & Estes, E.H. Evaluation of patient-care protocols used by various providers. New England Journal of Medicine, 1975, 292, 507-511.

Harless, W.G., Drennon, G.G., Marxer, J.J., Root, J.A., Wilson, L.A., & Miller, G.E. Genesys — A generating system for the Case natural language model. Computers in Biology & Medicine, 1973, 3, 247-268.

Hoffman, P.J. Physicians appraise other physicians: Improving the decisions of a medical specialty board. Oregon Research Institute Research Bulletin, 1974a, 14(4).

Hoffman, P.J. Quasi-automation of the medical specialist examination board. Oregon Research Institute Research Bulletin, 1974b, 14(18).

Holvey, D.N. (Ed.). The Merck manual of diagnosis and therapy. Rahway, N.J.: Merck, Sharp & Dohme Research Laboratory, Division of Merck & Company, Inc., 1972.

Kleinmuntz, B. (Ed.). The processing of clinical information by man and machine; Formal representation of human judgment. New York: Wiley, 1968.

Leaper, D.J., Horrocks, J.C., Staniland, J.R., & DeDombal, F.T. Computer-assisted diagnosis of abdominal pain using "estimates" provided by clinicians. British Medical Journal, November 1972, 11, 350-354.

McGuire, C.H., & Solomon, L. Clinical simulations. New York: Appelton-Century-Craft, 1971.

Nash, F.A. Differential diagnosis: An apparatus to assist the logical faculties. The Lancet, April 24, 1954.

Neufeld, V.R., Norman, G.R., Feighter, J.W. & Barrows, H.S. Clinical methods of medical students II: A cross-sectional analysis. Proceedings, Conference on Research in Medical Education, Association of American Medical Colleges, Washington, D.C. November, 1975.

Newell, A. & Simon, H.A. Human problem solving Englewood Cliffs, New Jersey: Prentice-Hall, 1972.

Slovic, P. & Lichtenstein, S. Comparison of Bayesian and regression approaches to the study of information processing in judgment. Organizational Behavior and Human Performance, November 1971, 6(6), 649-744.

Swender, P.T., Tummessen, W.W. & Oski, F.A. A computer-assisted diagnosis. American Journal of Disabled Children, June 1974, 127, 859-861.

Vinsonhaler, J.F., & Wagner, C.C. Technical manual for the basic information management system (Vol. 1). The Institute for Research on Teaching, Michigan State University, 1977.